

IMPLEMENTING A RELIABILITY CENTERED MAINTENANCE PROGRAM AT NASA'S KENNEDY SPACE CENTER

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Abstract: Maintenance practices have long focused on time based "preventive maintenance" techniques. Components were changed out and parts replaced based on how long they had been in place instead of what condition they were in. A reliability centered maintenance (RCM) program seeks to offer equal or greater reliability at decreased cost by insuring only applicable, effective maintenance is performed and by in large part replacing time based maintenance with condition based maintenance. A significant portion of this program involved introducing non-intrusive technologies, such as vibration analysis, oil analysis and I/R cameras, to an existing labor force and management team.

This paper discusses what is involved in an RCM program and how EG&G is implementing it at Kennedy Space Center on the facilities maintenance program. It discusses technical tools, management tools and people issues involved in achieving the goal of "better, faster, cheaper" in the facilities arena.

Key Words: Maintenance; Metrics; RCM; Reliability

The maintenance program is an integrated, closed loop, continuous improvement process that includes life cycle maintenance planning, asset risk assessment, runtime, calendar & condition based maintenance, outage coordination, facility condition assessment and cost accounting. The maintenance program is proactive in nature, reliability centered and is a true asset management program. Program effectiveness is measured in terms of asset availability, reliability and life cycle cost.

An essential element in the program is the computerized maintenance management system (CMMS) with the capability to interface electronically with subject matter specific software such as predictive maintenance software programs for vibration analysis. The software provides the traditional productivity and maintenance cost reports as well as asset condition and maintenance requirements reports. It generates work orders based on asset condition triggers and time based or usage based preplanned frequencies. The asset inventory, with pertinent data including risk codes and RCM analysis information, is contained in the CMMS. This enables Maintenance Engineers to trend equipment failures for further analysis, and is the means of continually improving the

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effectiveness of the assigned levels of maintenance associated with an asset or definable group of assets.

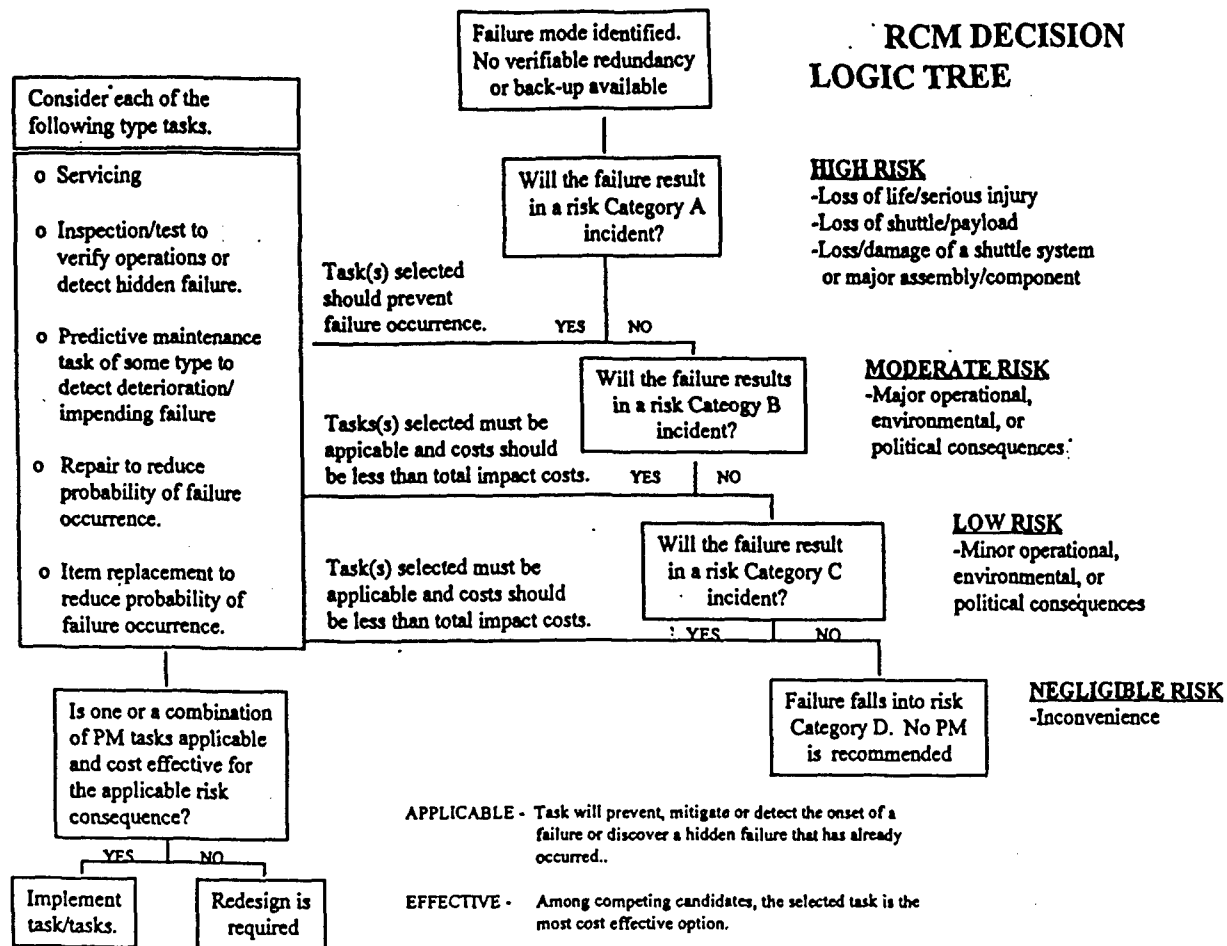
Components The Maintenance Program is a closed loop process that ensures continuous program improvement. The first functional component of the process is an accurate **inventory of assets** included in the maintenance program. It is critical to know **what** is being maintained and have it accurately identified in the CMMS.

Life Cycle Planning ensures the function of the assets is clearly defined, understood and documented and maintenance requirements are planned for the designed life of the asset. This occurs during the design process for new assets and is documented taking into account such things as ease of access to components, minimization of special tooling, incorporation of data for predictive maintenance condition trending, etc. Consideration is also given to the expected life of materials specified in the design and **program maintenance** requirements resulting from expiration of the materials useful life (i.e. repainting structures on a 7-8 year cycle, replacing roofing systems on 20 year cycles, etc.). The more routine recurring maintenance including preventive tasks (service, inspections and minor repair) and predictive testing will be identified utilizing the RCM methodology. For existing assets, this takes place during the RCM analysis.

Once the asset inventory is established and entered into the computerized information system and the function of the individual or defined group of assets is clearly understood and documented a **risk assessment** is performed. The risk assessment of the impact of a loss of function of the asset is performed to determine the appropriate asset risk category. Assets fall within four basic risk categories (high, medium, low or negligible) based on the lack of ability to support mission or the cost involved should there be a loss of asset function. This risk assessment is the first step in developing maintenance requirements under an RCM methodology.

A significant component of the program in terms of cost effectiveness is the methodology for determining maintenance requirements. The RCM philosophy is a departure from traditional methods of determining maintenance requirements. RCM logically incorporates the most effective mix of **reactive, preventive, predictive and proactive** maintenance practices and draws on their respective strengths. RCM applies the four maintenance practices where each is most appropriate based on the consequences of failure and the resulting impact to mission. This combination produces optimum reliability at minimum maintenance cost and the combined benefits far exceed those resulting from using any one maintenance practice. RCM incorporates the principle that any maintenance task performed must be proven to be applicable and effective. Applicable implies that, of the competing tasks, the selected task is the most cost effective option. Effective means that the performance of the task will prevent, mitigate or detect the onset of a failure or discover a hidden failure that has already occurred.

During an RCM analysis, engineers use a decision logic tree to assign the proper mix of maintenance. Figure 1.



This decision logic tree focuses on sustaining the reliability of assets in support of a defined mission. The RCM analysis is structured to implement the principle that no maintenance task will be performed unless it is justified. The criteria for justification are safety, reliability and cost effectiveness in deferring or preventing a specific failure mode. Because RCM is reliability based, statistical analysis and conditional probabilities of failure are important in determining the consequences of failure. The primary objective is to maintain the inherent reliability designed into the asset. The product of the RCM analysis is work procedures for both preventive and predictive maintenance that are captured in the CMMS. The performance schedule is also generated in the CMMS as a basis for initiating preventive/predictive maintenance.

The next program component, **Facility Condition Assessment (FCA)**, is important to maintenance engineers and managers as it provides feedback on asset maintenance effectiveness. The FCA is an asset inspection and engineering analysis of maintenance history, failure trends, any root cause failure analysis that might have been performed and any open or planned work requirements. The purpose of the FCA is to validate

maintenance requirements identified during life cycle planning, review and revise the effectiveness of the assigned mix of predictive, preventive and reactive maintenance, identify any new asset deficiencies that may have been detected during the assessment process, review planned maintenance work and review energy issues, if applicable.

Another important part of the FCA is validating the mission of the asset. Program requirements changes many times drive asset mission changes. When mission changes occur, the level of assigned maintenance may require adjustment due to changes in asset criticality. We perform FCAs on a five year cycle to coincide with the budget cycle. Knowing the asset mission, the asset maintenance history, the identified and planned maintenance requirements and the current condition of the asset, work can be prioritized and programmed for performance over the budget cycle. Existing maintenance procedures can be validated and adjusted as required, monitoring programs implemented and tests conducted on assets to further evaluate any suspected problems. The FCA provides a structured process for validating, justifying and prioritizing maintenance requirements.

An appropriate level of maintenance can not be assigned to an asset unless the consequences of failure of that asset are clearly understood. RCM forces focus on the product of a **system**, rather than on individual items within a system. As a result, many items which are critical to a system operation are found to have backups or work-arounds designed into the system, so a failure or loss of an individual item does not result in a system failure. An example of this may be in electric power distribution, where power to a specific facility is critical. The loss of the feeder cable will result in no power through that cable. It will not result in a power loss to the facility, however, because the facility has dual power feed from independent circuits, an emergency backup generator and an UPS. The system does not fail, only the component.

Risk assessment is the first step in determining maintenance levels. Four risk levels have been established, based on the consequences of failure; high, medium, low and no risk. High and medium risk codes are often associated with catastrophic failures, but because of the economic impact costs smaller failures can also fall into this area. If a facility suffers a loss of utilities and has no secondary feed (either onsite or portable), the people in that building will have to stop work and leave. This "impact cost", different from a repair cost, while not obvious to maintainers is real and must be a factor in evaluating the risk level. The RCM analysis is structured to implement the principle that no maintenance task will be performed unless it can be justified. The criteria for justification are **safety, reliability, and cost effectiveness** in deferring or preventing a specific failure mode. Because RCM is reliability based, statistical analysis and conditional probabilities of failures are important in determining the consequences of failure. The primary objective is to maintain the inherent reliability designed into the equipment. Figure 2 graphically ties all the parts together.

INTEGRATED MAINTENANCE PROGRAM MODEL

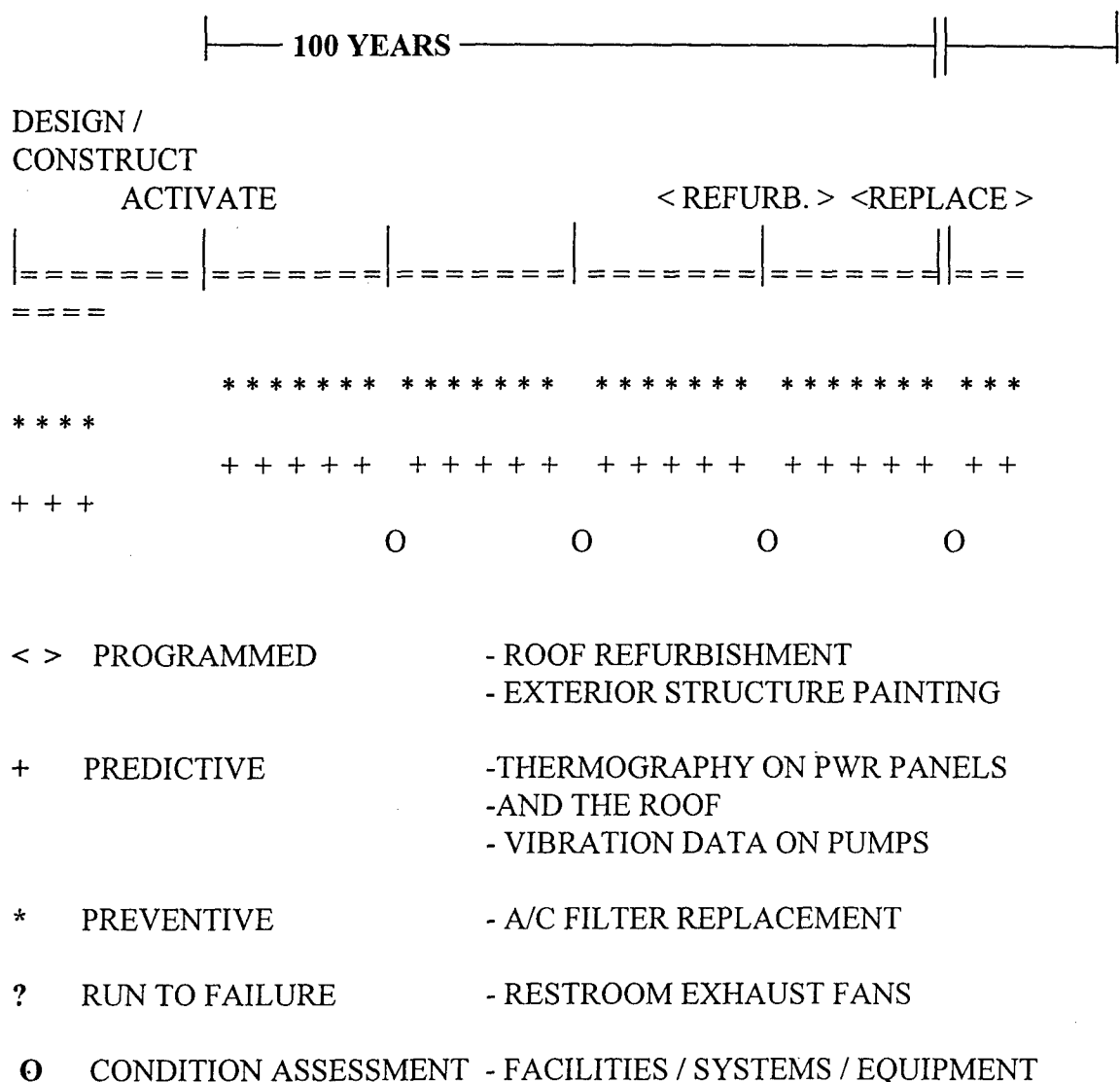


Figure 2

In this model, it has been determined during the design that the facility is expected to support its defined function for 100 years. The roof of the facility, given the climate the facility will be subjected to, will require major refurbishment after approximately 20 years of service. Therefore, as part of the life-cycle plan, a major refurbishment is identified 20 years from date of facility activation. In addition, while determining the exterior paint specifications, historical data and engineering studies indicate facilities require repainting every five years. This, too, is added to the life-cycle plan as identified program level maintenance requirements. Infrared thermography is also identified on a frequent basis. It is used to perform a condition assessment of the roof and the electrical panels throughout the facility in lieu of previously assigned labor intensive PM tasks. Air filters are replaced on a regularly scheduled basis.

Predictive Maintenance, also known as Predictive Testing and Inspection (PT&I), can determine the condition of the equipment and provide various trend indicators. Interpretation of these indicators allows potential functional failure to be forecast so corrective maintenance can be performed to preclude failure. Working as a complement to the PM program a PT&I program can:

- o Help determine the condition of a component and identify required repairs before that component fails.
- o Conserve resources by performing maintenance on an as-required basis rather than on a calendar frequency or a run-time basis.
- o Minimize down time.

The effectiveness of each applicable PT&I test is examined to determine which test or combination of tests will be used. Any test by itself may not give a good representation of the overall condition of each piece of equipment on the system. However, certain combinations will give a very good indication of equipment condition. Comparisons with previous tests provides trend data useful in condition assessment analysis.

Historically, the focus of maintenance has been the Preventive Maintenance (PM) program. Electrical and mechanical equipment experience deterioration over time that eventually causes it to fail. PM is used to slow this deterioration, ensuring the equipment's operational life. A properly conducted program reduces overall operating costs, aids mission effectiveness, safety, and assures the continued preservation, usefulness, and performance of assets. The PM program, coupled with the other elements of the overall maintenance program, allows engineers to be aware of equipment condition so that sufficient time is available for the systematic planning and scheduling of required repair work.

Preventive maintenance consists of the planned and scheduled maintenance tasks that are periodically performed on equipment to avoid a breakdown. The frequency is based on calendar date, rate of utilization (routine), or condition which is determined by trending data collected through the application of PT&I technologies. The PM program consists of the following:

- o Inspections of mechanical, electrical and other physical structures, installed equipment and systems such as motors, pumps, compressors, faucets, light switches, etc.
- o Inspections are performed on a periodic, pre-determined basis in an effort to determine the degree of operating efficiency and whether equipment deficiencies exist.
- o Routine servicing of equipment including lubrication, cleaning and changing filters, minor adjustments and parts replacement, and condition reporting.
- o Formalized evaluation and work generation system which ensures discovered, uncorrected deficiencies are entered into the normal planning and scheduling system.

Run-to-failure is a reactive component because it is based on the premise that no maintenance task that improves the reliability of the F/S/E in a cost effective manner has been identified. Users call a trouble desk to report breakdowns on run-to-failure items. When the corrective action required is beyond the scope of a trouble call, if engineering is required, or if material must be ordered, the trouble call is changed to a repair work order. As with other work orders, labor, materials and material costs are tracked in a CMMS. This information is then sent to a computer history file which can be retrieved later for use in F/S/E condition assessments, making repair/replace decisions, failure trending, and other engineering analysis.

Maintenance Effectiveness The effectiveness of the maintenance program must be measured and validated. Long term effectiveness is monitored through the facility condition assessment while short term effectiveness is determined using failure trending analysis, which highlights failure trends on like equipment. This advanced notice gives time to take action to prevent catastrophic failures.

Failure trending codes are developed by maintenance engineers with support from field technicians. These codes are used by the technicians in the field to track and classify failures and are recorded in the CMMS. The coding structure, coupled with existing report filter capabilities, allows a relatively quick analysis of failure data. If a problem is suspected, a more detailed analysis is performed. Reports provide information on the following elements: 1) number of loss-of-function events; 2) cause of loss; 3) disposition of cause; and 4) corrective action taken.

PROGRAM MEASUREMENTS (METRICS) The following metrics are reported to measure the progress and of cost effectiveness of the maintenance program.

a. ***Equipment Availability***

$$\% = \frac{\text{Hours System/Equipment is Available to Run at Capacity}}{\text{Total Hours During the Reporting Time Period}}$$

b. ***Maintenance Overtime Percentage***

$$\% = \frac{\text{Total Maintenance Overtime Hours During Period}}{\text{Total Regular Maintenance Hours During Period}}$$

c. ***Percent of Emergency Work to Routine Work***

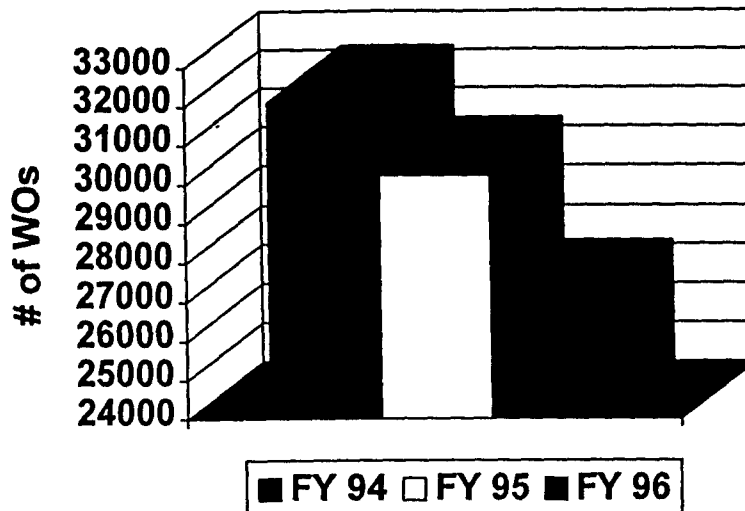
$$\% = \frac{\text{Total Emergency Hours}}{\text{Total Maintenance Hours}}$$

d. *Percent of Faults Found in Thermographic Survey*

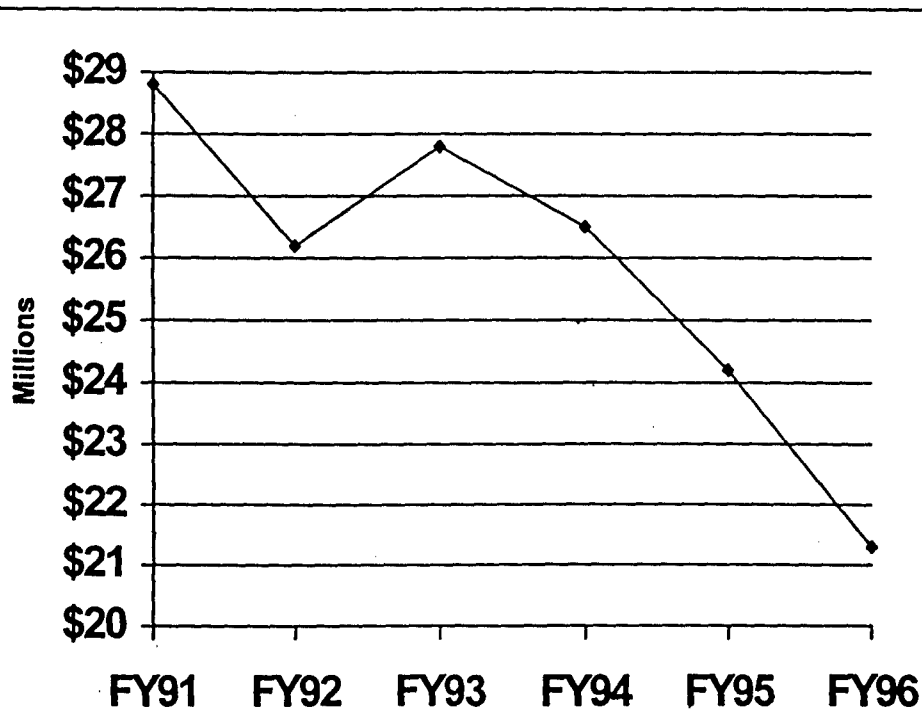
$$\% = \frac{\text{Number of Faults Found}}{\text{Number of Devices Surveyed}}$$

e. *Total cost of maintenance per year*

Figure 3 shows some results obtained by the program as measured by two metrics.



ACTUAL MAINTENANCE COSTS



Lessons Learned Many of the lessons we learned are available from existing texts, both technical and management. It is perhaps inevitable that lessons have to be learned individually in order to be understood, and so many of the lessons presented here are of an obvious nature. By far our biggest finding was the value of repetition. By definition, a cycle of continuous improvement implies doing the same thing over and over and getting a bit better each time. Implementing a reliability centered maintenance program involves changing the way people think and work. Training, explanations, briefings, analysis, making changes and tracking results were done on an individual basis, shop by shop. Selecting a visible, intuitive initial technology is also an important point. Laser alignment was easily demonstrated, learned and understood; vibration monitoring is more involved and less readily grasped. I/R cameras are so advanced the operation is simple; point and shoot technology allows anyone to actually see the temperature difference between a loose connection and a proper one. As we were able to show results, we began to build a cadre of supporters who functioned as champions in their own right.

When we began this project, we went through a developmental phase, an implementation phase and are now in an operational mode. It is no longer a phase - we have achieved a shift in the way we do business. The very nature of the process ensures it will repeat itself over and over - a cycle of continuous improvement. This program is not something we do - it is a way of getting things done in an efficient, cost effective and risk appropriate manner.

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